# Status of the ATF Damping Ring BPM Upgrade Project

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for the ATF DR BPM collaboration

# ATF DR BPM Collaboration

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# Outline

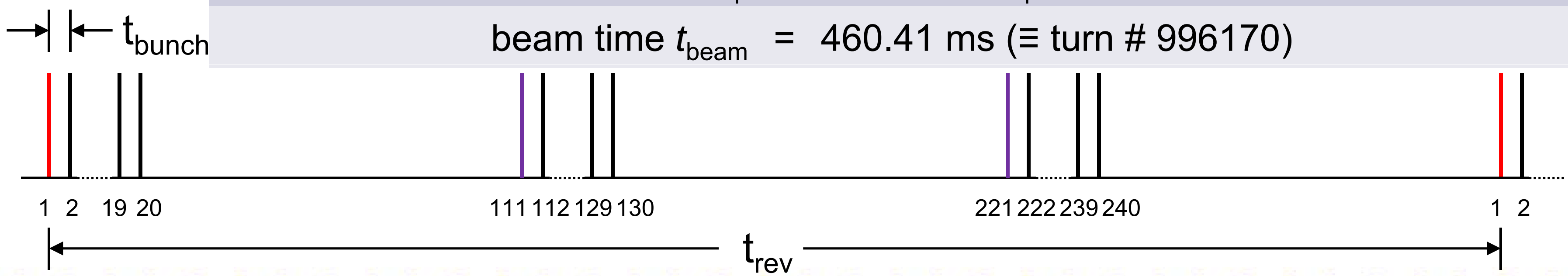
- Motivation
- Some background information on the ATF damping ring and it's beam parameters
- Characteristic of the ATF button-style BPM pickup
- Overview and details of the new BPM hardware
- Project history
- Preliminary results
- Next steps…
  - **This presentation certainly is incomplete, in particular it does not address the tremendous firm- and software efforts related to the project!**

# Motivation

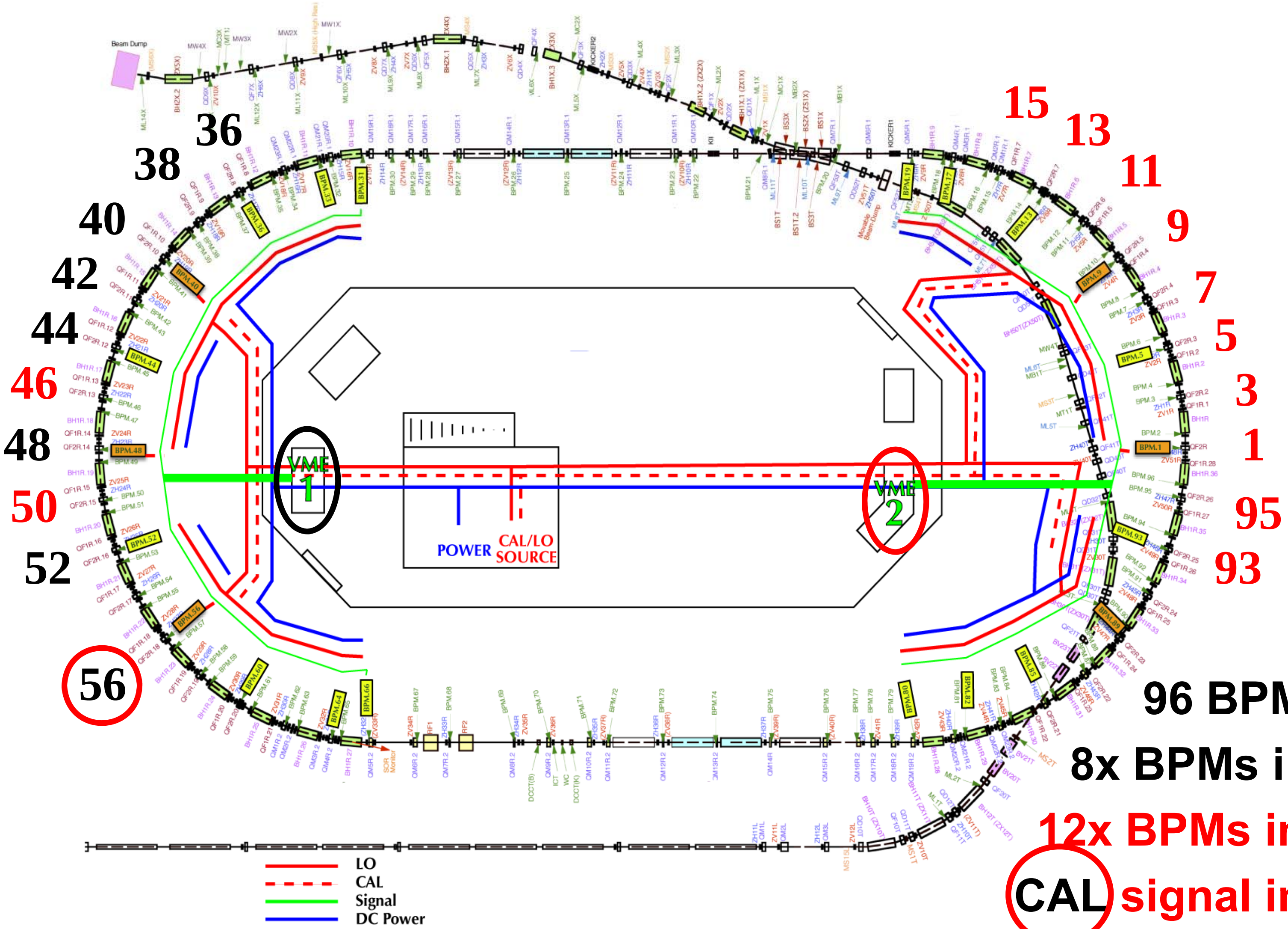
- ILC damping ring R&D at KEK's Accelerator Test Facility (ATF):
  - **Investigation of the beam damping process (damping wiggler, minimization of the damping time, etc.)**
  - **Goal: generation and extraction of a low emittance beam ($\varepsilon_{vert}$ < 2 pm) at the nominal ILC bunch charge**
- A major tool for low emittance corrections: a high resolution BPM system
  - **Optimization of the closed-orbit, beam-based alignment (BBA) studies to investigate BPM offsets and calibration.**
  - **Correction of non-linear field effects, i.e. coupling, chromaticity,…**
  - **Fast global orbit feedback(?)**
  - **Necessary: a state-or-the-art BPM system, utilizing**
    - a broadband turn-by-turn mode (< 10 µm resolution)
    - a narrowband mode with high resolution (~ 100 nm range)

# The ATF Damping Ring

| Machine and Beam Parameters | | |
|---|---|---|
| beam energy $E$ | = | 1.28 GeV |
| beam intensity, single bunch | ≈ | ~ 1.6 nC ≡ $10^{10}$ $e^-$/bunch ≡ $I_{bunch}$ = 3.46 mA |
| beam intensity, multibunch (20) | ≈ | ~ 22.4 nC ≡ 0.7 $10^{10}$ * 20 $e^-$ ≡ $I_{bunch}$ ≈ 48.5 mA |
| accelerating frequency $f_{RF}$ | = | 714 MHz |
| revolution frequency $f_{rev}$ | = | $f_{RF}$ / 330 = 2.1636 MHz ≡ $t_{rev}$ = 462.18 ns |
| bunch spacing $t_{bunch}$ | = | $t_{RF}$ / 2 = 2.8011 ns |
| batch spacing $t_{batch}$ | = | $t_{rev}$ / 3 = 154.06 ns |
| horizontal betatron tune | ≈ | 15.234 ≡ $f_h$ ≈ 506 kHz |
| vertical betatron tune | ≈ | 8.567 ≡ $f_v$ ≈ 1200 kHz |
| synchrotron tune | ≈ | 0.0045 ≡ $f_s$ ≈ 9.7 kHz |
| repetition frequency $f_{rep}$ | = | 1.56 Hz ≡ $t_{rep}$ = 640 ms |
| beam time $t_{beam}$ | = | 460.41 ms (≡ turn # 996170) |



# ATF Damping Ring BPMs



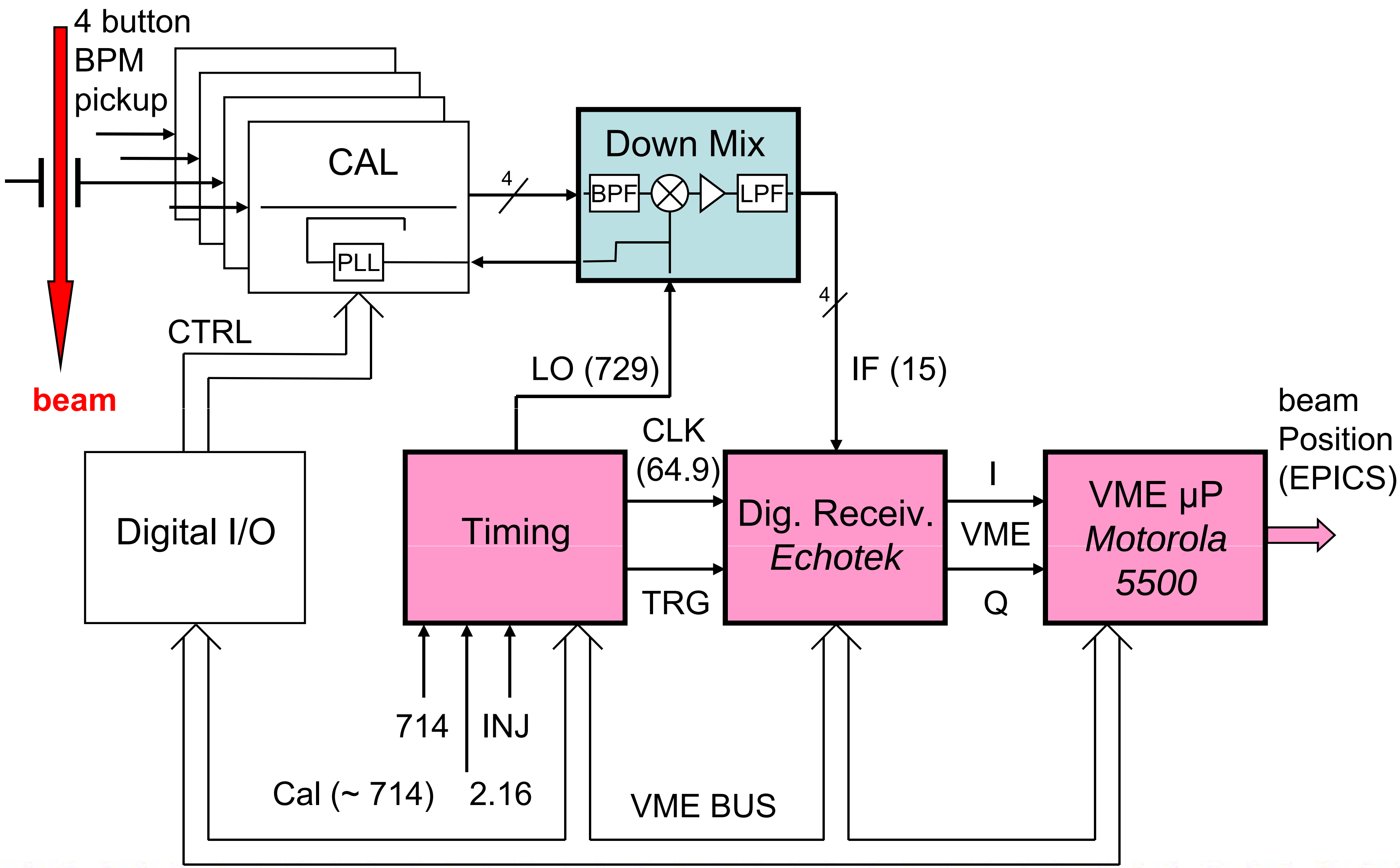

**96 BPMs total:**

**8x BPMs in Feb07**

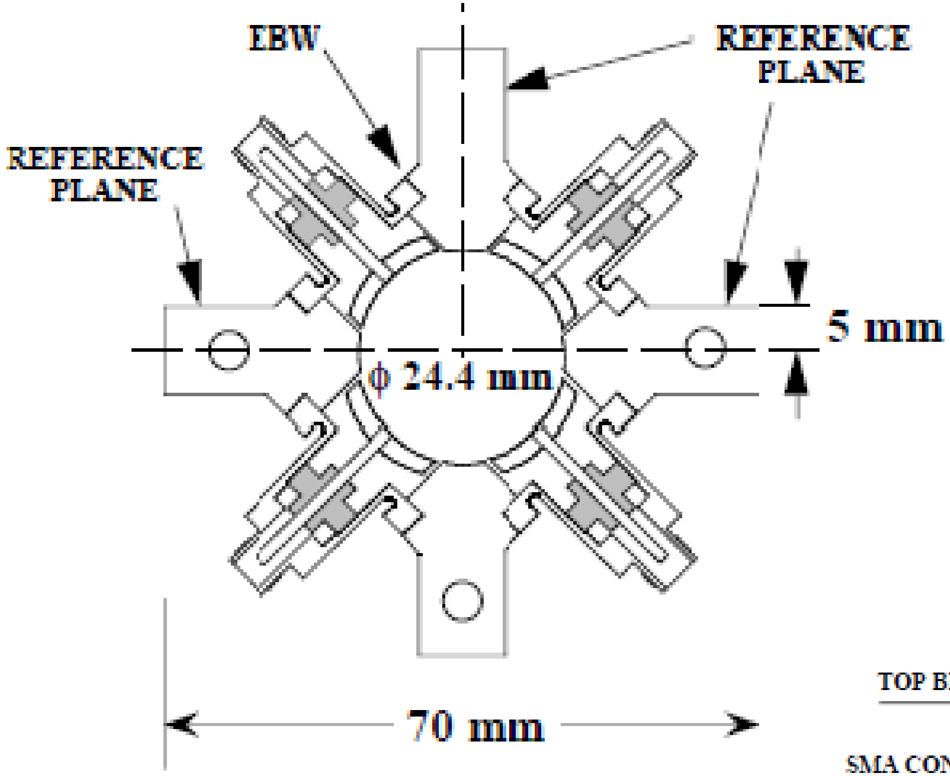
**12x BPMs in May07**

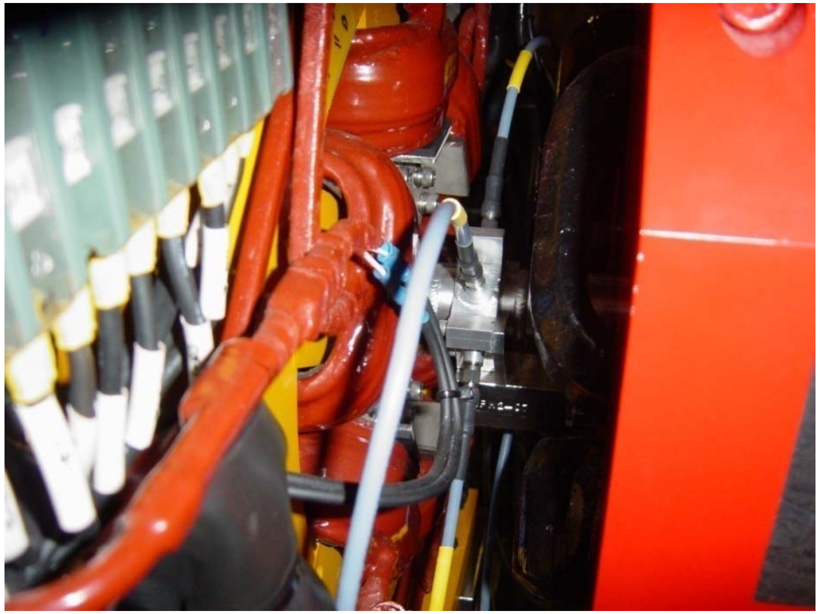
**CAL signal in May07**

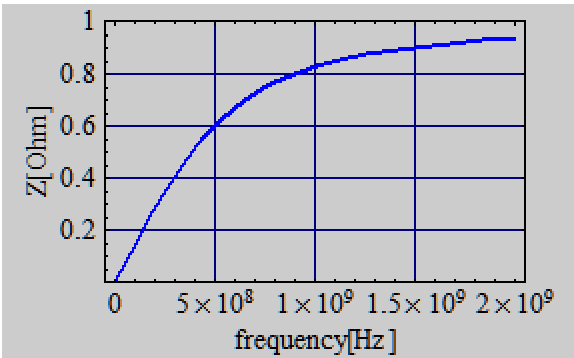
# BPM Hardware Overview



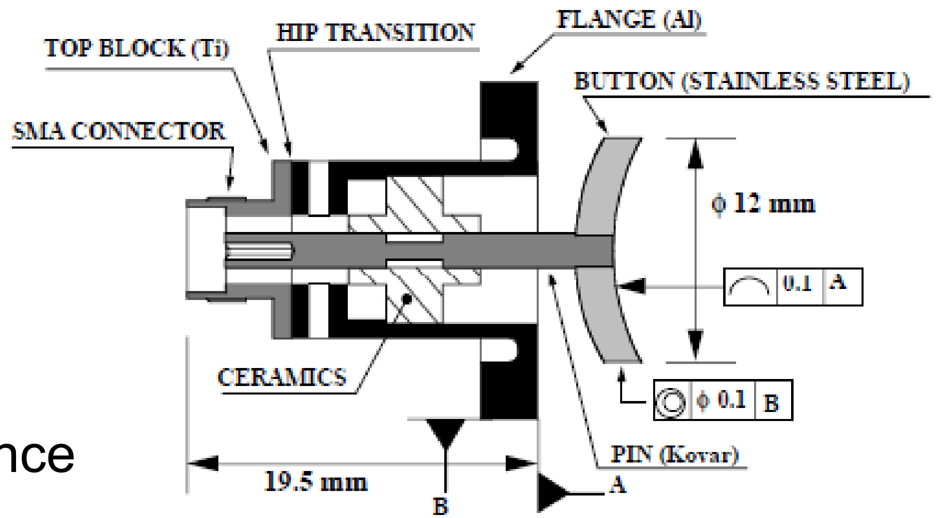
# Button-style BPM Pickup



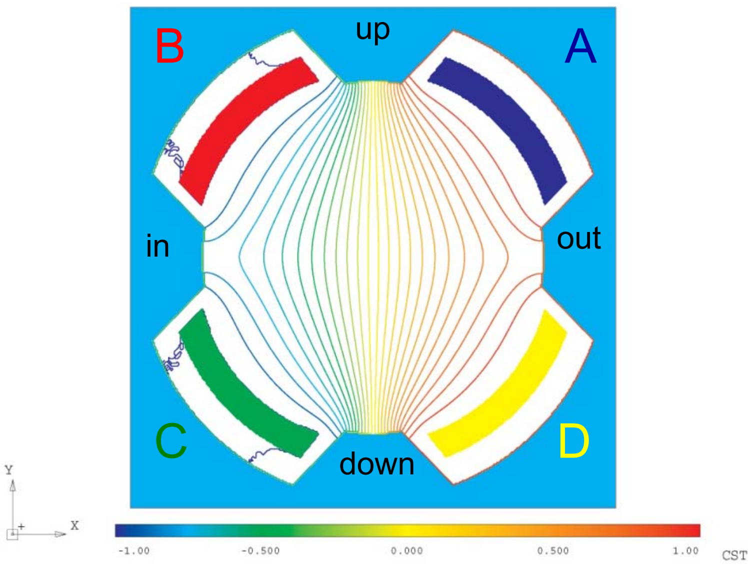



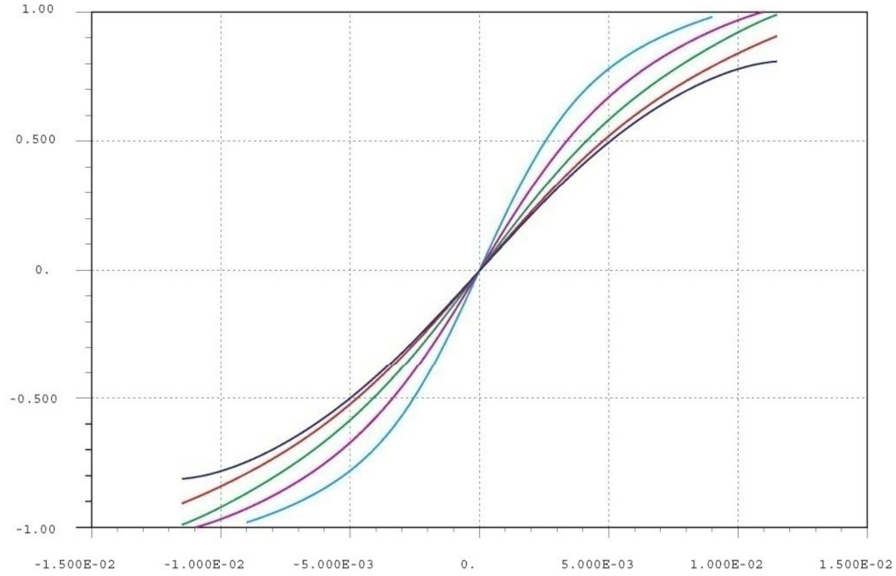



Button:
transfer
impedance



# Button-style Pickup Characteristic




## Normalized horizontal and vertical potentials:

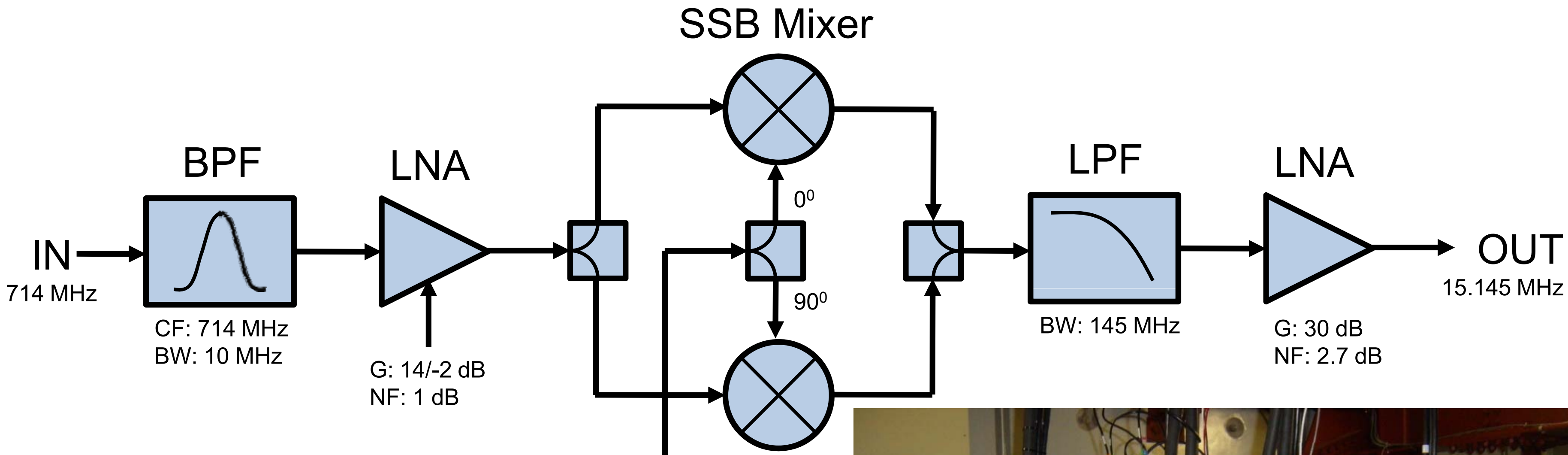
$$\phi_H = \frac{(A+D)-(B+C)}{A+B+C+D} \qquad \phi_V = \frac{(A+B)-(C+D)}{A+B+C+D}$$

## 1D polynomial fit ("on axis" calibration):

$$Pos[mm] = 9.35\phi + 1.00\phi^3 + 7.79\phi^5$$

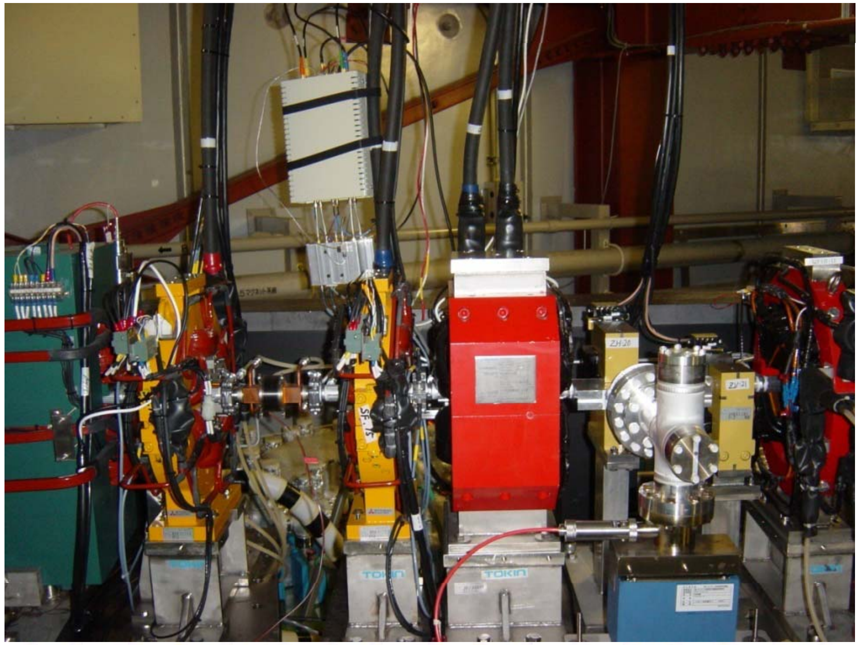
2D polynomial fit is prepared, but not yet implemented.

# Analog Signal Processing

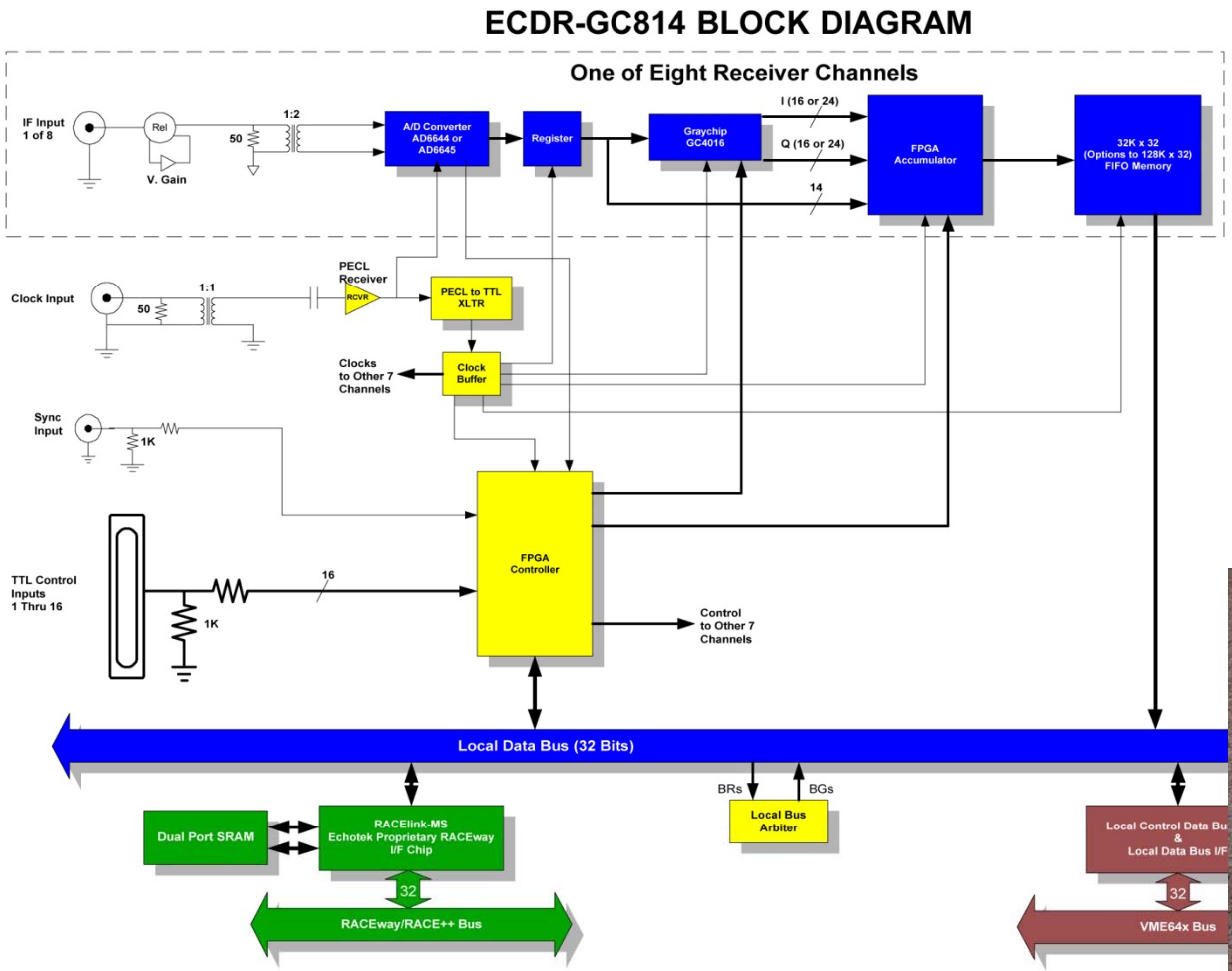



4-ch analog downconverter (located in the tunnel):

- Selective inputs (714 MHz BPF, ~ 100 ns ring-time)
- Gain switchable, low-noise, high IP3 input gain stage
- Image rejection (SSB) mixer
- 15.1 MHz high gain IF stage

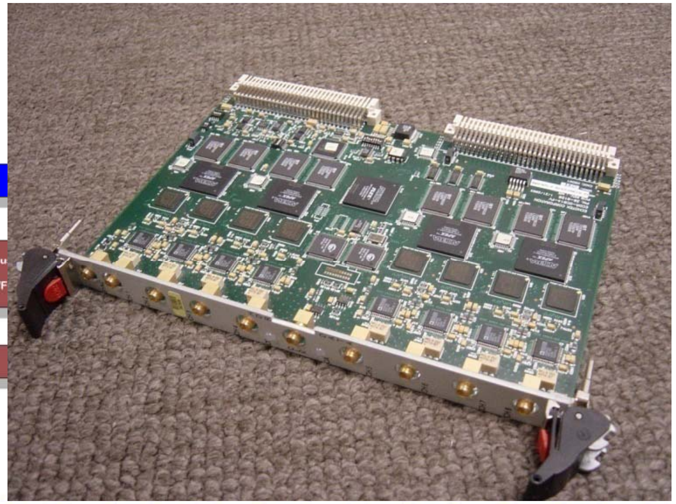


# Digital Signal Processing

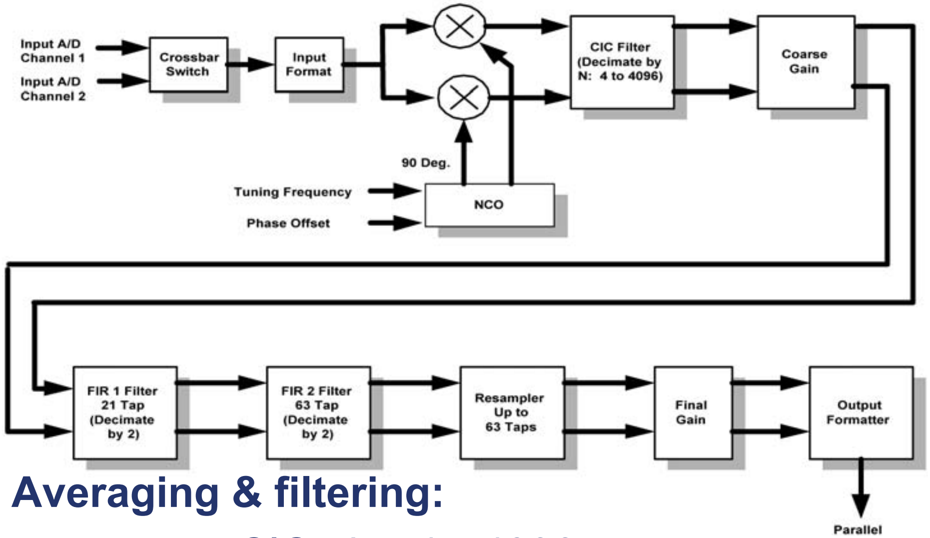



***Echotek* digital receiver:**

- 8-ch VME 64x module
- *Analog Devices* 14-bit 105 MS/s AD6645
- Each channel: *Texas Instruments* 4-ch GC4016 “Graychip” digital downconverter



# Digital Signal Processing (cont.)




**Averaging & filtering:**

- 5-stage CIC, dec 4…4096
- 21-tab CFIR, dec 2 (or 1)
- 63-tab PFIR, dec 2

**Wideband Mode (BW ~ 1 MHz):**

- total decimation: 8
- 8-tab running ave. FIRs

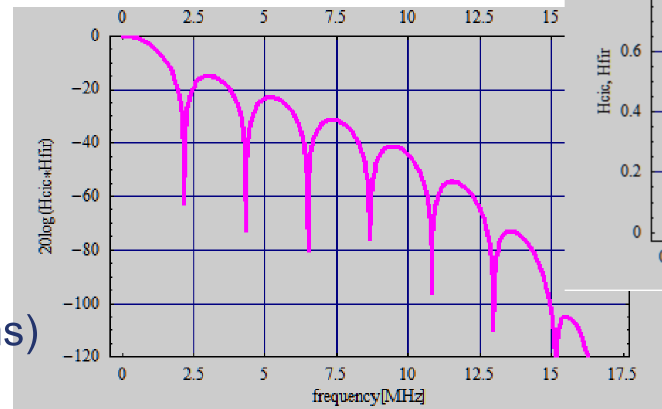
**Narrowband Mode (BW ~ 1 kHz):**

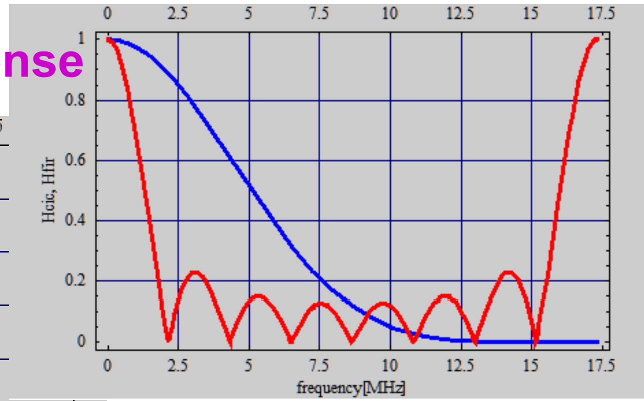
- total decimation: 10988, $t_{dec}$: 158.7 µs, 1280 pt (~ 200 ms)
- 11 & 32-tab RRC FIRs

***Graychip* digital downconverter:**

- 4 independent channels per ADC
- NCO set to $f_{IF}$ = 15.145 MHz (downconvert to DC baseband)
- ADC clock set to 32 samples per revolution: $f_{CLK} = 32{*}f_{rev}$ = 69.2 MHz
- Decimation and filtering for the broad- and narrowband operation, using CIC and FIR digital filters

**WB mode magnitude response**



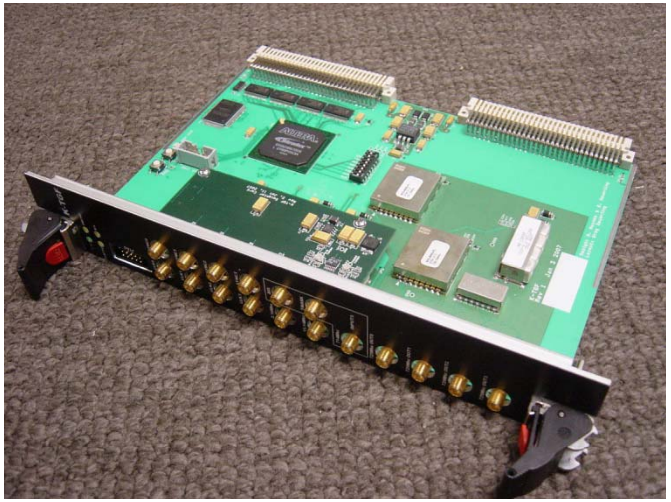




**WB CIC response**

**WB FIR response**

# Other Hardware

- VME Timing module:
  - $f_{CLK} = f_{RF}$*32/330 = 69.236 MHz clock signals (4x)
  - $t_{rev}$ = 462.2 ns turn marker signals (4x), 0…115 double-buckets (2.8 ns) delayable
  - To $f_{RF}$ phase-locked $f_{LO}$ = 729.145 MHz
  - Auxiliary $f_{rev}$ and $f_{IF}$ signals

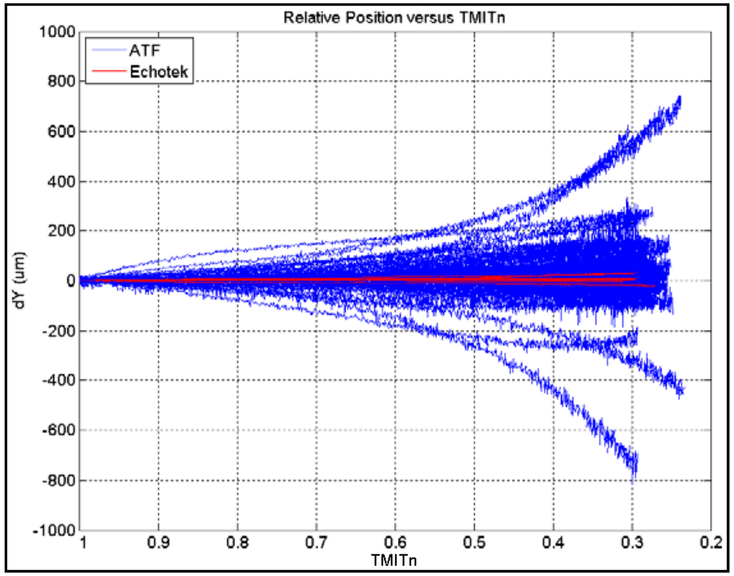


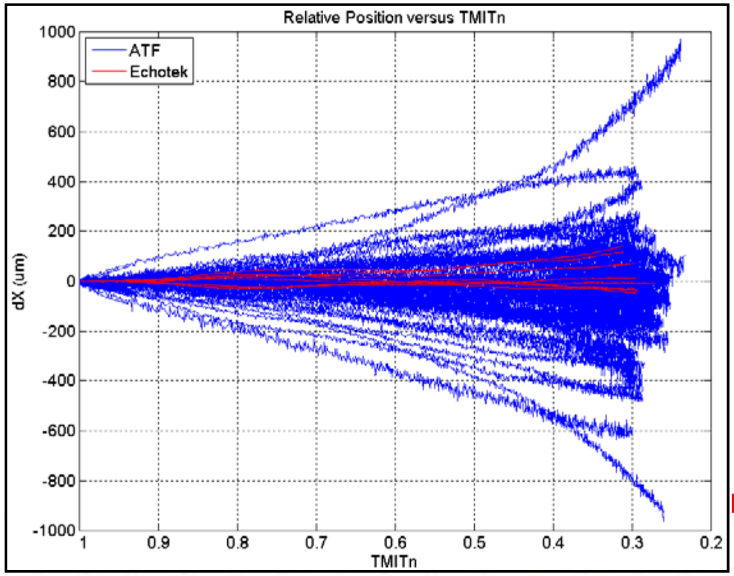
- *Motorola* 5500 VME CPU:
  - Data collection and normalization
  - Box-car post-processing filter (20 ms)
  - Local diagnostic and control software
  - EPICS control interface
- Calibration unit (prototype):
  - To $f_{RF}$ phase-locked $f_{CAL} \approx$ 714 MHz (*Analog Devices* ADF4153)
  - In-passband, through button-BPM calibration
  - $2^{nd}$ *Graychip* channel for downconversion

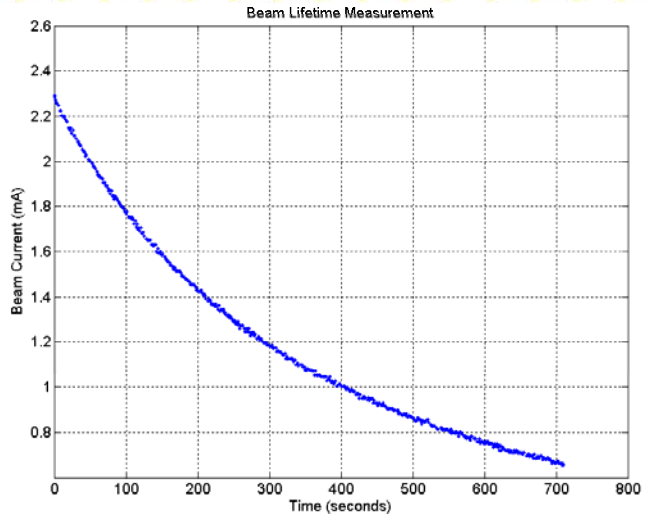
# Project History

- February 2006 visit: KEK/SLAC:
  - **Proof of principle installation & commissioning**
  - **Read-out hardware for 8x button-style BPMs:**
    - 4x temporary *Echotek* boards (older style, no *Graychip* DDC).
    - 8x downmix modules, plus spares.
    - LO signal generator, cabling, crates, PS, auxiliary systems.
- February 2007 visit: KEK/SLAC(3)/Fermilab(6)
  - **New installation & commissioning (again 8x BPMs).**
  - **6 dedicated, plus parasitic machine shifts (focus on system installation and commissioning).**
- May 2007 visit: KEK/SLAC(3)/Fermilab(6)
  - **Upgrade to 20x BPMs (limited by downmix module availability) in 2x VME crates.**
  - **7 dedicated, plus parasitic machine shifts (focus on commissioning and some systematic beam studies).**

# First Results (February 2006)

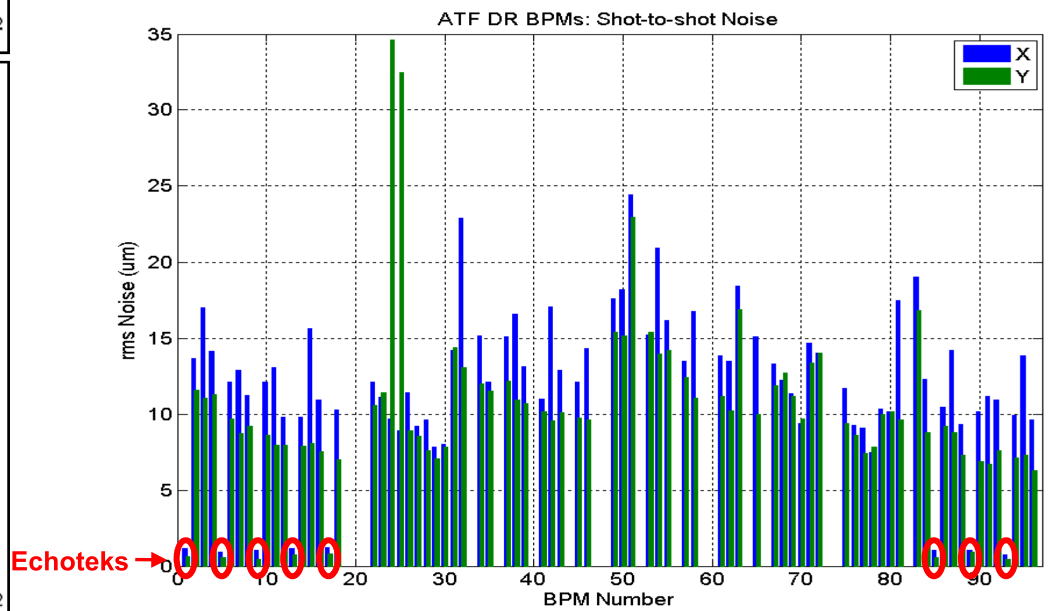


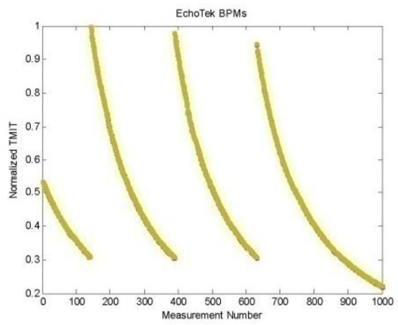




Accomplishments:

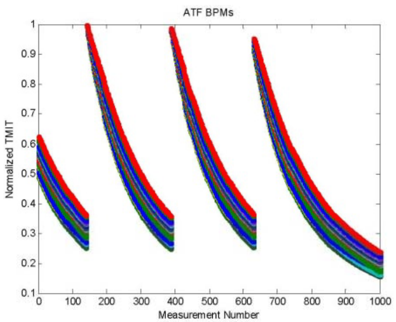
- Improved observed resolution (~10 -> ~1 μm)
- Reduced intensity dependence



# (Very) Preliminary Results 2007

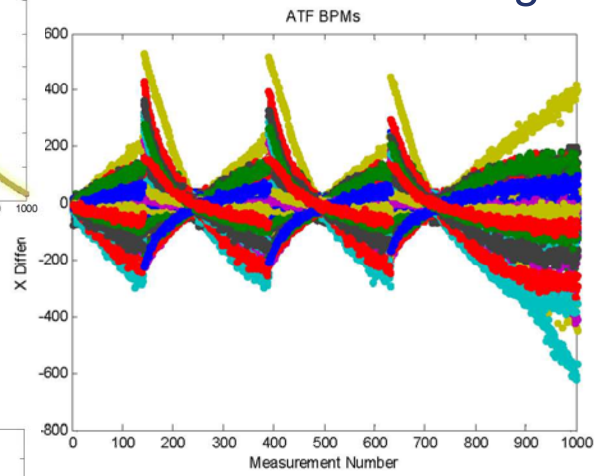


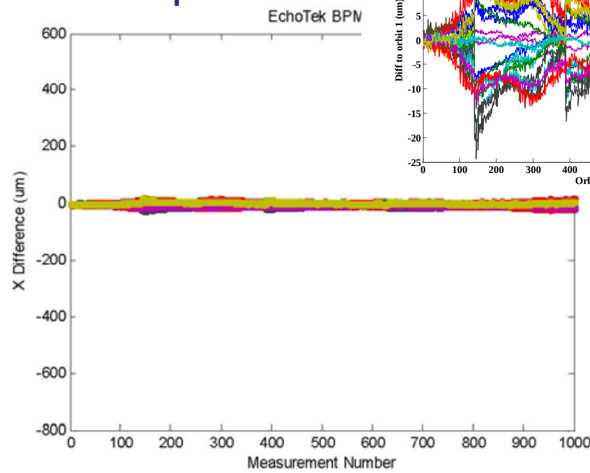

Normalized intensities

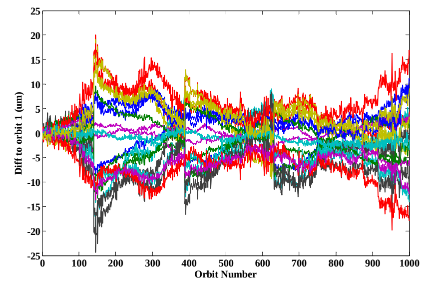



Horizontal Position

Plot range: +600/-800 μm



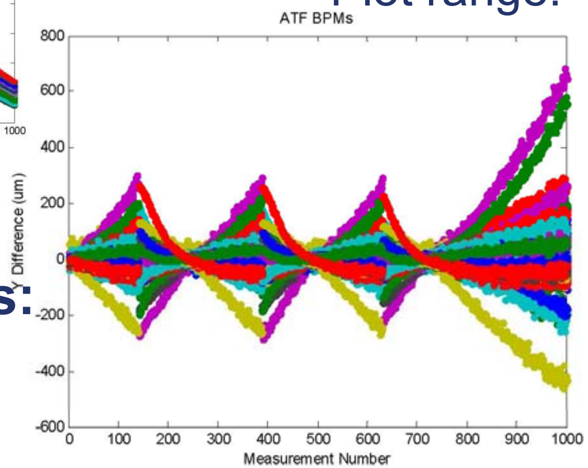



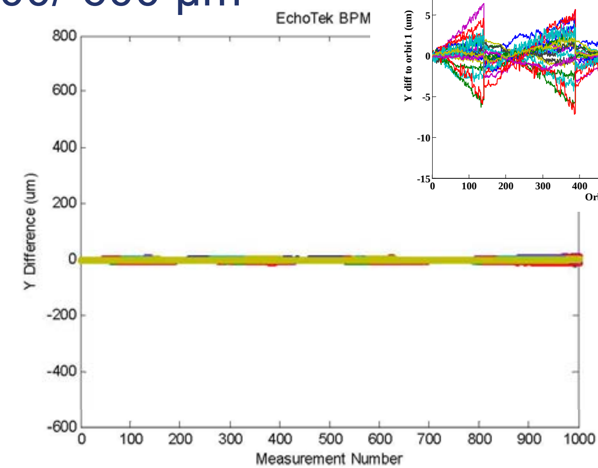



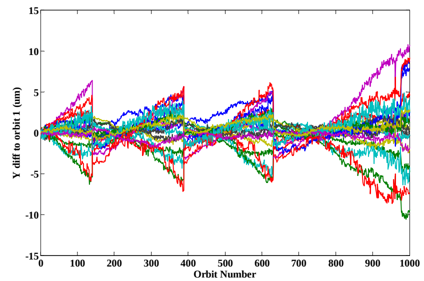

Plot range: ± 25 μm

Vertical Position

Plot range: +800/-600 μm




Plot range: ±15 μm

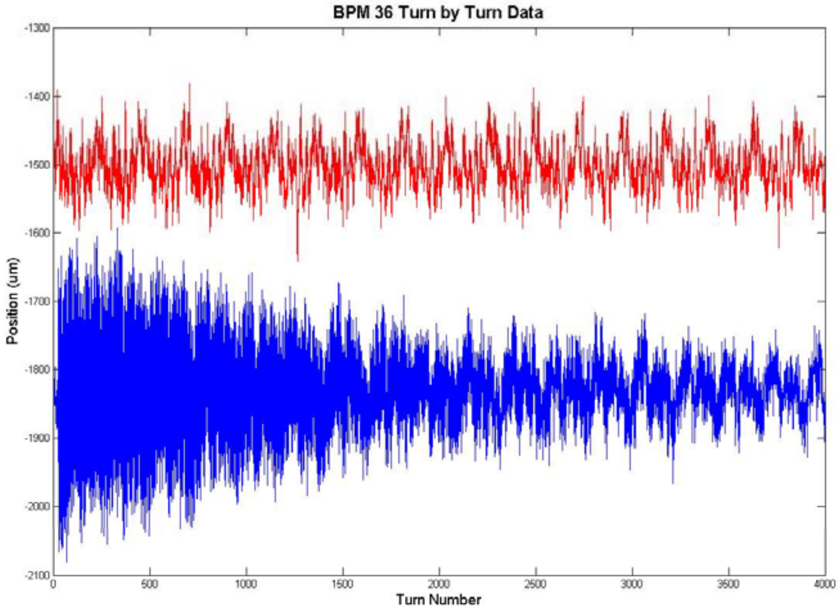
**Scrubbed mode studies:**
Intensity dependence

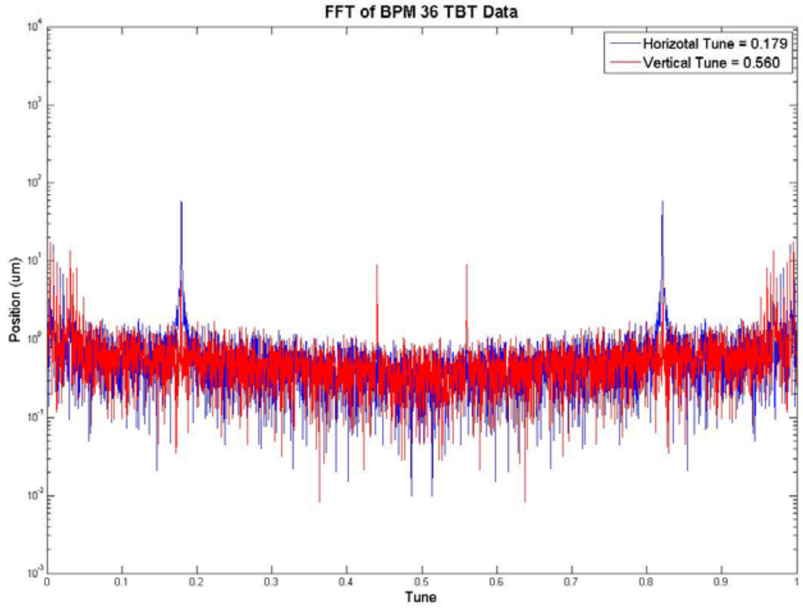
# Results 2007: BBA (070227, 070302)

| Y BBA (um) | ET | +/- | ATF | +/- |
|---|---|---|---|---|
| QF2R.10 | 343.38 | 6.44 | 15.15 | 17.10 |
| | 316.49 | 34.40 | -105.14 | 174.00 |
| QF2R.11 | 112.68 | 2.99 | 300.89 | 55.70 |
| | 107.87 | 5.16 | -89.69 | 165.00 |
| QF2R.12 | -72.69 | 5.07 | -172.12 | 85.70 |
| | -91.84 | 14.20 | -798.00 | 2040.0 |
| QF2R.13 | -188.03 | 1.19 | -177.83 | 323.00 |
| | -174.37 | 37.20 | -82.01 | 54.50 |

| dET | dATF |
|---|---|
| | |
| 26.9 | 120.3 |
| | |
| 4.8 | 390.6 |
| | |
| 19.2 | 625.9 |
| | |
| 13.7 | 95.8 |

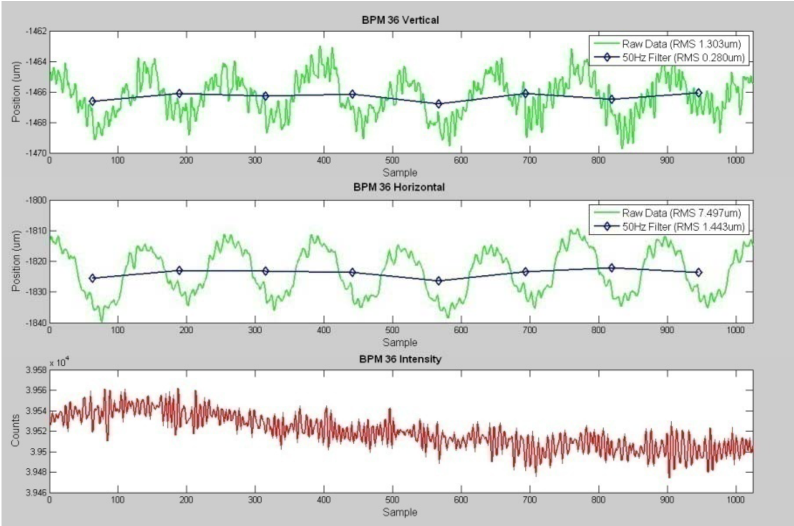
# Results 2007: Broadband TBT

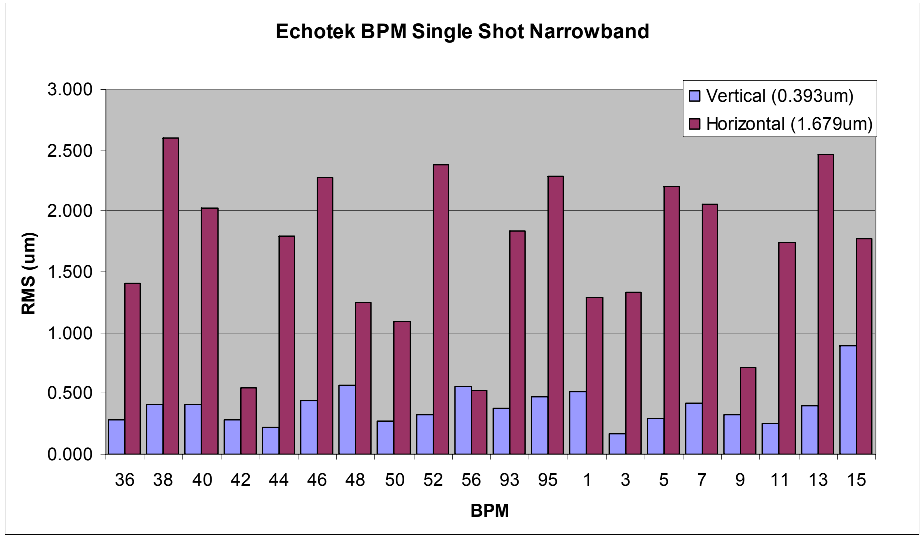



- Turn-by-Turn data BPM #36 (pinger: On)
- Identifying hor. and vert. tune lines (387 kHz, 1.212 Mhz) as well as sync. tune lines (n x 9.7 kHz).
- Observed short time, broadband TBT resolution: few µm!

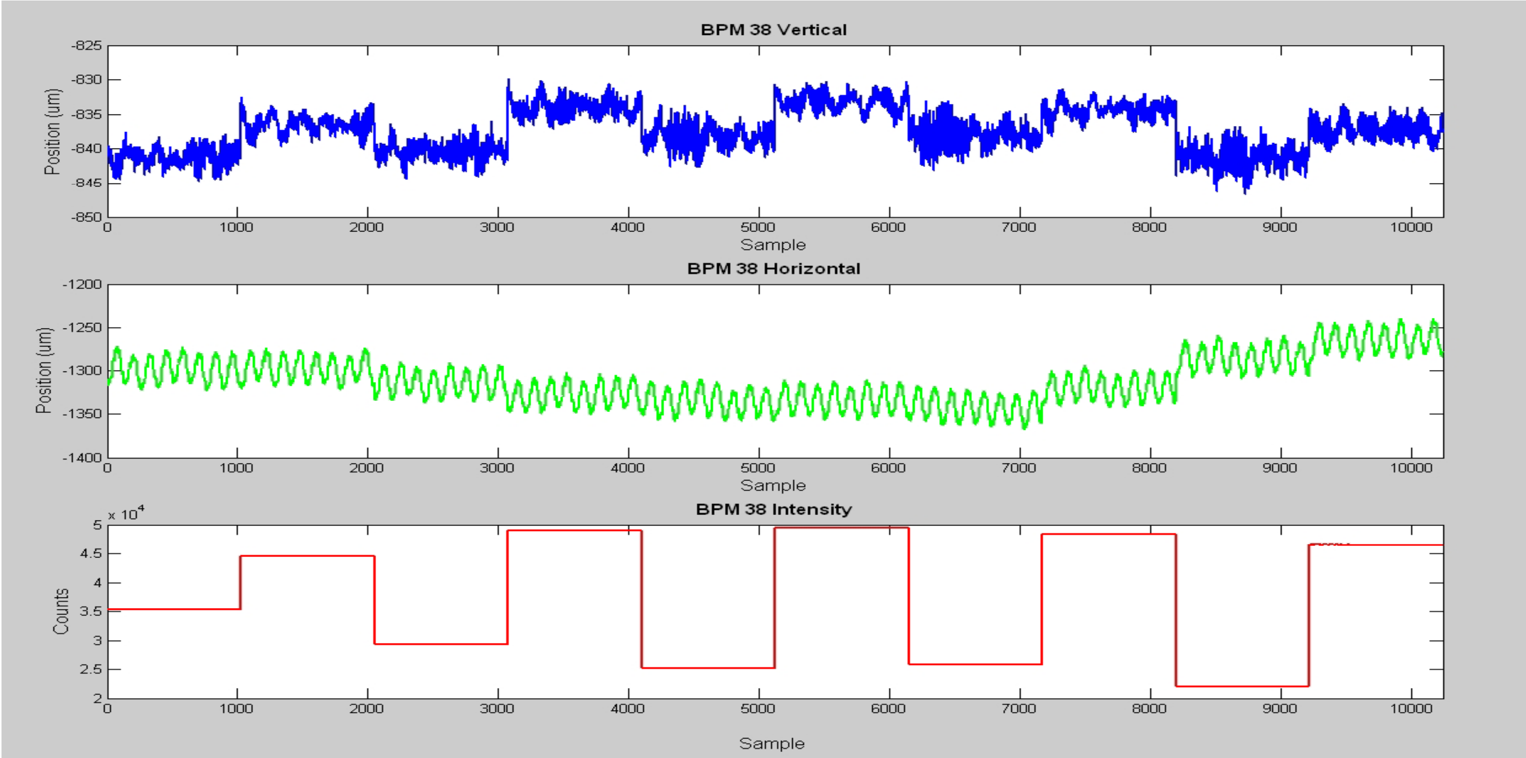
# Results 2007: Narrowband Mode



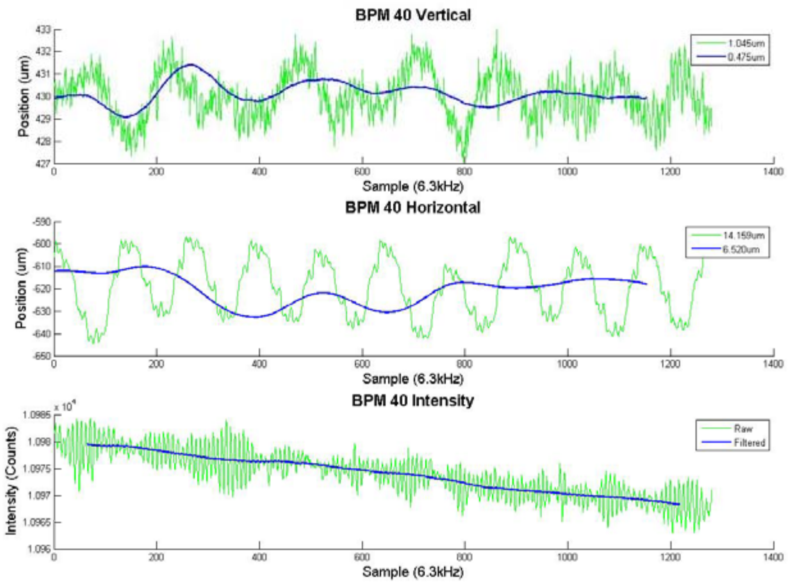

- Optimized Narrowband Mode to remove 50Hz
  - **Lengthened the *Echotek* collection time (160ms shown)**
  - **Apply 126 tap box and decimate filter to further average and remove 50Hz**
  - **Very strong 50Hz signal in horizontal but also apparent in vertical**
- After filtering see 0.4 μm RMS vert. and 1.7 μm RMS hor. for single shot
  - **Expect electronics to provide same resolution on horizontal and vertical**
  - **Suggests orbit motion is contributing to RMS**
- Data being further analyzed using SVD technique
  - **Find correlations which can be related to electronics problems or orbit motion**
  - **Need to understand sources of correlations**

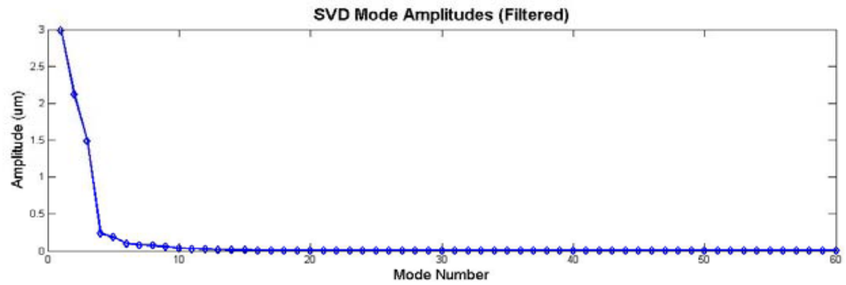
# Results 2007: NB Shot-to-Shot

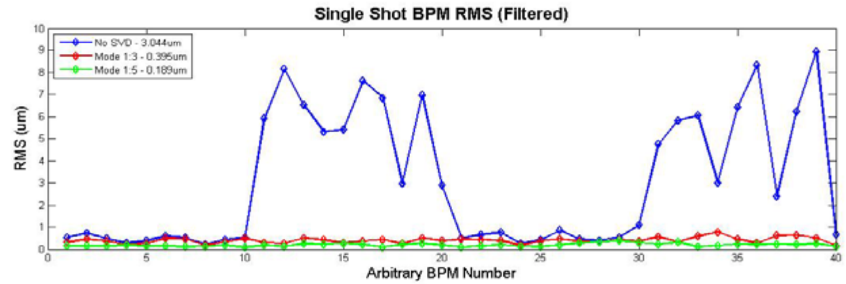



- Shown is Raw Narrowband Data for 10 shots
  - **Raw data is 160ms from 500k turn for each shot**
  - **Each shot was taken 1 minute apart over 10 minutes**
- Observe BPM position change
  - **Need to understand whether the effect is electronics or orbit**

# Results 2007: Single Shot SVD

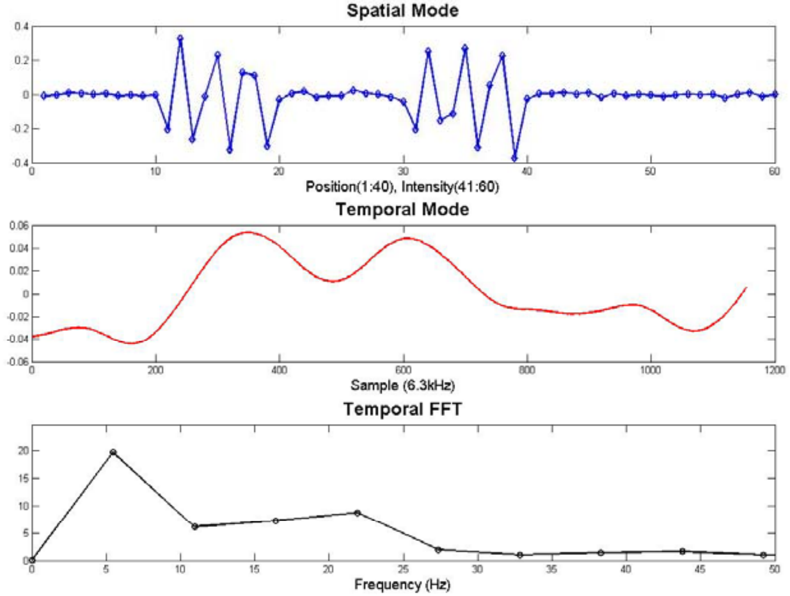


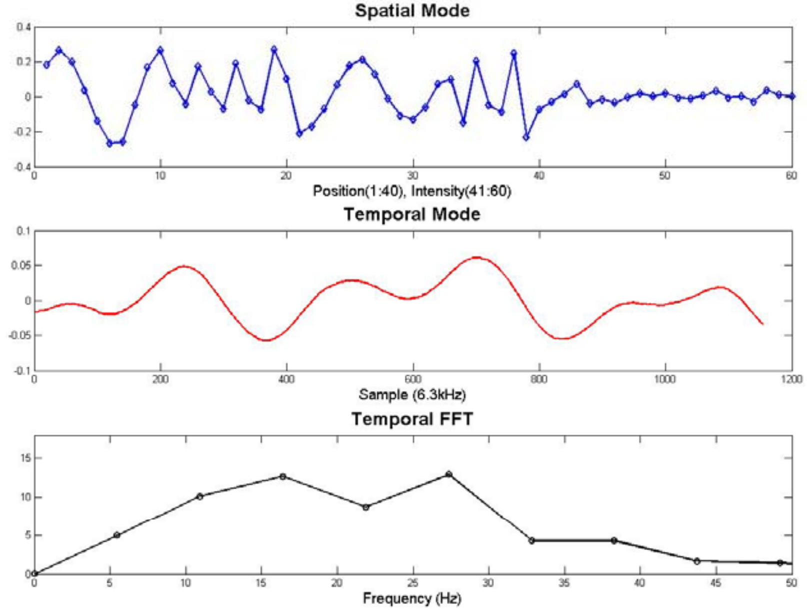




- Data filtered by 126 tap box to average and remove 50Hz
- Observe strong orbit motion in the horizontal plane!
- Remove the motion to find “real” BPM resolution
  - **400 to 200 nm range (preliminary!)**

# Results 2007: SVD Mode Examples



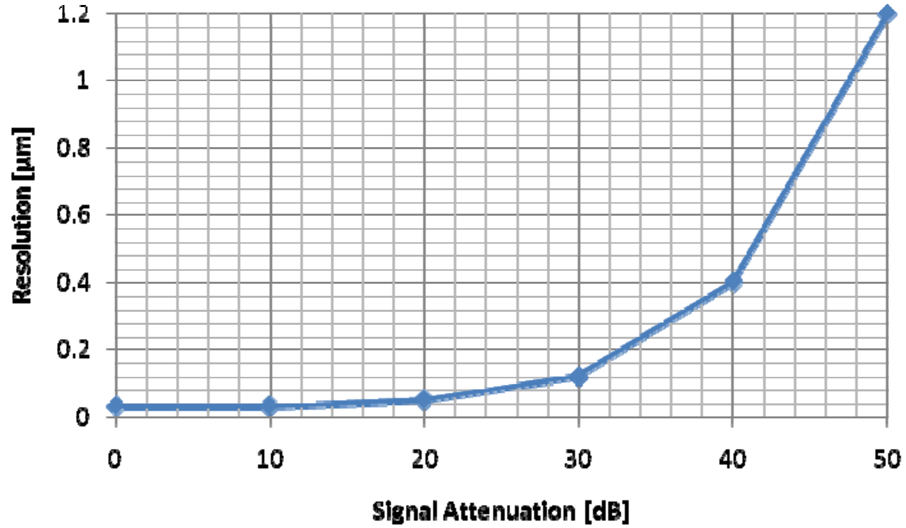

- SVD Mode 1
  - **Clearly shows horizontal orbit motion**
  - **Not “BPM physical”**
- SVD Mode 5
  - **Shows single period in vert. BPM and 3 periods in hor. BPM**
  - **Seems to be “real”!**

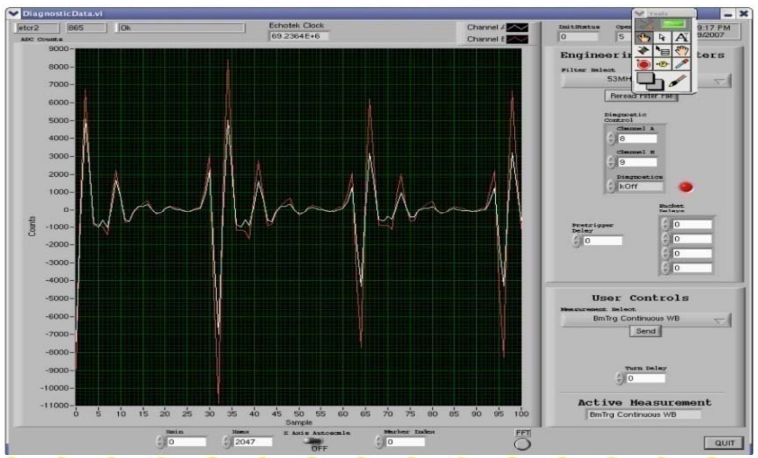
# Results 2007: Resolution Limit

Theoretical:

- ADC SNR: 75 dB
- Process gain: 40.4 dB
- NF 1st gain stage: ~ 1 dB
- CAL tone level: -10 dBm
- Splitter attenuation: 6 dB
- Effective gain: ~ 100 dB
- BPM sensitivity: 240 μm/dB
- **Calculated equivalent resolution: ~ 20 nm**

**CAL tone resolution measurement on BPM #56: ~ 30 nm(!)**



Single bunch raw ADC data (not a CW signal)

# Next Steps…

- Summer/Fall 2007:
  - **Development on an improved analog front-end downmix&calibration section (production prototype), SLAC/Fermilab collaboration effort**
    - Switchable input gain/attenuation
    - IF lowpass/bandpass matched to DDC Nyquist cut-off
    - 4 stage PLL CAL signal generator
    - Fully remote control ($I^2C$, etc.)
    - Improved RF enclosure
  - **Various firm- and software improvements, e.g. diagnostic layer via EPICS.**
  - **Reliability improvements on hard- and software.**
  - **10 (12) channel timing boards**

# Next Steps… (cont.)

- Fall/Winter 2007:
  - **Testing of the new downmix&cal prototype at ATF**
  - **Testing of the new timing generator modules at ATF**
  - **Implementation and tests of software improvements**
    - Additional EPICS features
    - Time and frequency data
    - Calibration with DDC frequency hopping
  - **Systematic beam studies and analysis.**
  - **Test of a turn-by-turn based coupling correction method (?)**
  - **Series production of downmix&cal modules**
- Winter/Spring 2008:
  - **Full system upgrade, using Fermilab *Echotek* spares (loan basis) and the new cownmix&cal modules.**
  - **Installation, commissioning and testing.**
  - **Expansion of the system to extraction-line BPMs?**